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ELECTROLYTIC EFFECT ON A CURRENT CARRYING CONDUCTOR

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ABSTRACT. Effects due to superimposition of electrolytic current on a current carrying conductor are studied by direct measurement of the potential differences using a high precision potentiometer. The positive terminal of the electrolytic current was connected to (1) the positive end of the heated platinum wire (the electrolytic current adding the heating current) and (2) the negative end of the heated wire (the electrolytic current opposing the heating current). In both the cases the potential differences across the heated platinum wire are calculated by assuming point to point variation of the current along the wire. The agreement between the calculated and measured values is remarkable for small heating currents However at higher heating currents the measured values are found to be lower than the calculated values. This lowering is due to the increase in the leakage current along the wire in the electrolyte, as the conductivity of the electrolyte increases with the increase of electrolytic current and also with the rise in temperature of the electrolyte in the vicinity of the heated wire

INTRODUCTION

Heat transfer in fluids that are subjected to an electric field has been studied by Senftleben (1931). Similar such problems were then studied by Arajs and Legvold (1958) in different gases and at different pressures. Mixon, Chon and Beatty (1959) reported the changes in heat transfer coefficient from a heated surface due to electrolytic gas evolution. More recently Bhand *et al* (1963, 1963, 1965) have reported the variation in heat transfer coefficient at different ionic currents superimposed upon electrically heated thin platinum wire transferring heat at a small rate in a weak electrolyte Their contention was that when the so called resistance of the platinum wire decreases, it happens due to the increase in the heat transfer coefficient, whereas the increase in the resistance was due to the decrease in the heat transfer coefficient. Gaur, Bhatnagar and Dubey (1964) using a similar arrangement as that of Bhand *et al* have found that there is no adequate evidence to show any marked change in the heat transfer coefficient. This effect is purely an electrical phenomenon due to the superimposition of heating and electrolytic currents on the platinum wire. The change of resistance attributed by Bhand *et al* is actually the change of potential difference.

The purpose of the present investigation is to measure the potential difference due to the superimposition of electrolytic current on a current carrying platinum wire, directly by a high precision potentiometer, and to study the effect in greater details.

EXPERIMENTAL

A schematic diagram of the equipment used in the present investigation is shown in Fig. 1 A fine platinum wire (0 015 cm in diameter and 15 2 cm in length) is dipped horizontally in a weak electrolyte (here tap water) in a large tub

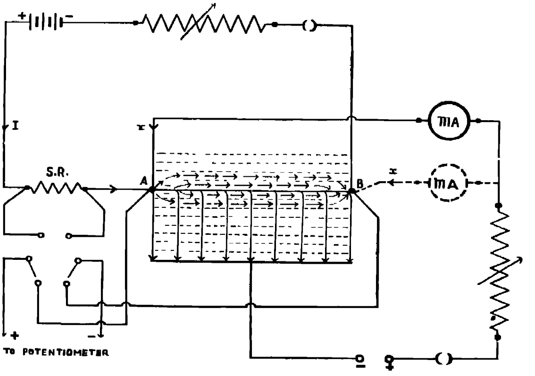

Fig 1 Circuit Diagram

at 28°C The platinum wire is surrounded by a co-axial cylinder and the electrolytic current is produced by applying a potential difference between the cylinder and one end of the platinum wire from a D C Compound Generator G.E.C. F 2A The remote temperature of the bath was kept constant within 0.5°C.

A heating current is passed through the platinum wire which is kept constant and is measured by a vernier potentiometer by measuring the potential difference across a standard resistance of 1 ohm in series with the wire The potential difference developed across the platinum wire is also measured with the same potentiometer.

Firstly, the potential difference across the platinum wire is measured at different heating currents and effective resistance is then found out by dividing the measured potential difference with the respective currents (I). A graph is then plotted between effective resistance R_e and current squared (I^2) Fig 2.

Secondly, the positive end of the platinum wire (as shown at A in Fig. 1) is made the positive electrode for the electrolytic current and at each value of heating current (I) the platinum wire is subjected to different electrolytic currents upto 1000 mA. (current densities 1 396 amp./sq.cm.) and the resultant potential difference on the platinum wire is measured keeping I constant Fig. 3 solid lines are the plot of measured potential differences versus electrolytic current (x) for different values of heating currents ranging from 0 to 2 0 amps.

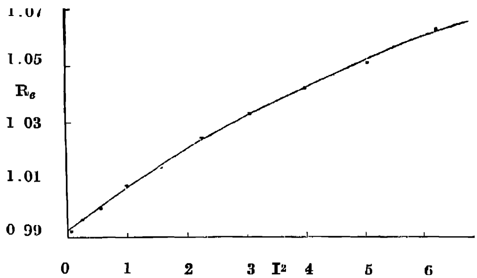

Fig. 2. Plot of Effective resistance R_e versus heating current squared I^2.

Thirdly, the electrolytic current was fed from the negative end of the platinum wire (as shown at B in Fig. 1) still keeping it as positive electrode for the electrolytic current. The resultant potential differences were then again measured for the same values of heating and electrolytic currents. Fig 4 solid lines are the plot of the measured potential differences versus electrolytic current for different values of I.

THEORETICAL CONSIDERATIONS

(1) When the positive end of the heated platinum wire is connected to the positive terminal of electrolytic current, it is quite evident that the electrolytic current varying from x to 0 will flow along the wire. Taking any length dl and ρ as the resistance per unit length of the wire, the potential difference across the element will be

$$\rho dl(I+i)$$

where i is the electrolytic current in the element dl and is a functin of l.

that is $i = 0$ at $l = 0$ (end B of Fig. 1)

and $i = x$ at $l = l$ (end A of Fig.1)

Hence the total potential difference across the wire will be

$$\sum_{0}^{l} \rho \, dl(I+i)$$

$$= \sum_{0}^{l} \rho I dl + \sum_{0}^{l} \rho i dl$$

$$= \rho l I + \rho l \frac{x}{2}$$

$$= \rho l \left(I+\frac{x}{2}\right)$$

$$= R_e \left(I+\frac{x}{2}\right)$$

where $\quad pl = R_e$

The effective resistance R_e at any instant will depend upon the heating power R_eI^2 and therefore, it is necessary that to know the effective resistance R_e, the heating power R_eI^2 must be known. Considering the current flowing in the wire from $(I+x)$ to I, the power will be

$$\sum_0^l \rho dl(I+i)^2$$

$$= \sum_0^l \rho I^2 dl + \sum_0^l 2\rho I i dl + \sum_0^l \rho i^2 dl$$

$$= \rho l I^2 + \rho l I x + \rho l \frac{x^2}{3}$$

$$= \rho l (I^2 + Ix + x^2/3)$$

$$= R_e (I^2 + Ix + x^2/3).$$

Therefore, for a particular electrolytic current x at a heating current I the effective resistance R_e is found out from I^2 versus R_e graph for $(I^2+Ix+x^2/3)$ current squared value and that this value of R_e is used to calculate the potential difference across the wire Viz. $R_e(I+x/2)$. The points marked cross (X) and curves represented by dotted lines in Fig 3 represent the calculated potential differences at different electrolytic currents.

(2) Similarly, when the negative end of the platinum wire is made positive terminal for the electrolytic current, the current flowing in the wire varies from I to $(I-x)$ and hence the heating power will be

$$\sum_0^l \rho \, dl(I-i)^2$$

$$= \sum_0^l \rho I^2 dl - \sum_0^l 2\rho I i dl + \sum_0^l \rho i^2 dl$$

$$= \rho l I^2 - \rho l I x + \rho l \frac{x^2}{3}$$

$$= \rho l (I^2 - Ix + x^2/3)$$

$$= R_e (I^2 - Ix + x^2/3).$$

The effective resistance R_e is found out from the graph of R_e and I^2 for $(I^2-Ix+x^2/3)$ and this value of R_e is used for calculating the resultant potential differ-

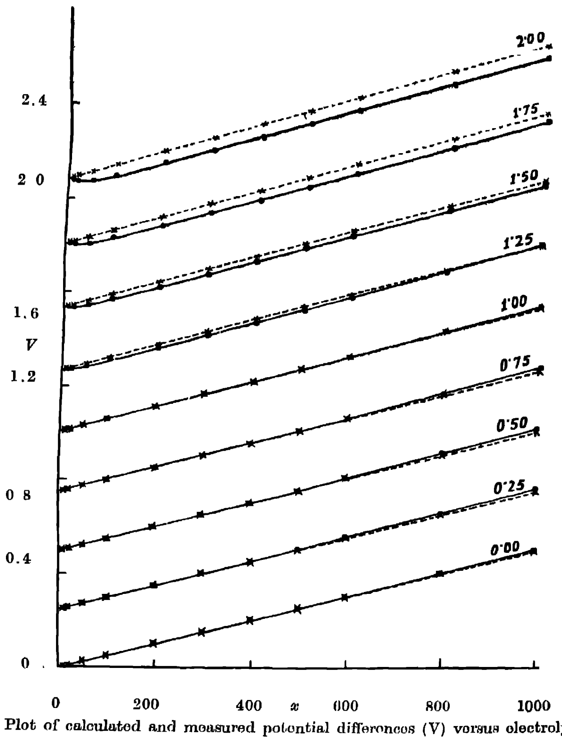

Fig. 3. Plot of calculated and measured potential differences (V) versus electrolytic current (x) for electrolytic current adding the heating current.

Since here $\quad i = x$ at $l = 0$ (end B of Fig. 1)

and $\quad i = 0$ at $l = l$ (end A of Fig 1)

The resultant potential difference in this case will be

$$\overset{l}{\underset{-}{\Sigma}} \rho dl(I-i)$$

$$= \sum_0^l \rho I dl - \sum_0^l \rho i dl$$

$$= \rho l\left(I - \frac{x}{2}\right)$$

$$= R_0(I - x/2).$$

The points marked by cross (X) and curves represented by dotted lines in Fig. 4 represent the calculated potential differences in this case.

Tables (1) and (2) illustrate the examples of calculating the potential differences in the two cases for $I = 2.0$ amps. The corresponding measured potential differences are also shown for the purpose of comparison.

(3) Whenever a current I is passed in a conductor (wire) dipped in an electrolyte it is very clear that the whole of the current I will not pass through the wire, but a portion of it i'_β, in the form of leakage current will pass through the

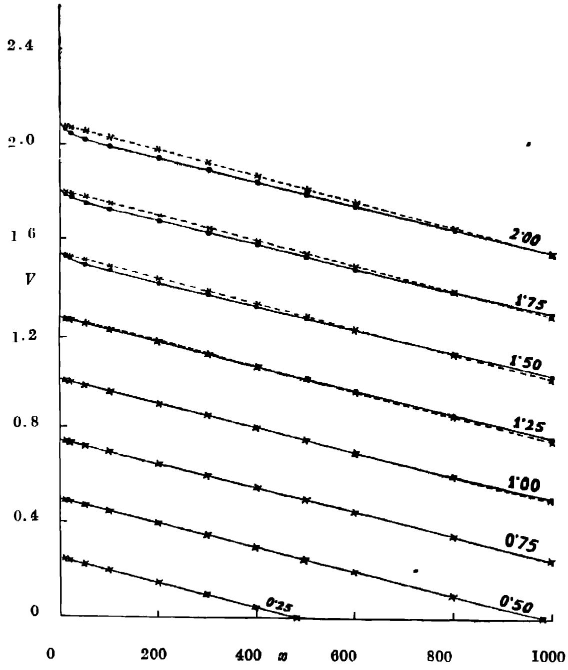

Fig. 4 Plot of calculated and measured potential differences (V) versus electrolytic current (x) for electrolytic current opposing the heating current.

electrolyte depending upon its conductivity. Thus if R is the actual resistance of the wire then

$$R(I-i_{\beta}) = R_e I$$

When an electrolytic current is passed, the conductivity of the electrolyte increases and after attaining a maximum value becomes constant Due to this increase in the conductivity of the electrolyte the value of the leakage current increases say by an amount i'_{β} and hence the net potential difference in the two cases will be $R_e\left(I-i'_{\beta}+\frac{x}{2}\right)$ and $R_e\left(I-i'_{\beta}-\frac{x}{2}\right)$.

INTERPRETATION OF RESULTS

(1) In figures 3 and 4 looking to the calculated and measured values of the potential differences across the platinum wire we find that upto 1 0 ampere of heating current where the increase in the leakage current that is i'_{β} is very small (which is also evident from the observations of dR by Gaur, Bhatnagar and Dubey, 1964) the two values are almost identical. However when the increase of i'_{β} becomes effective, that is above 1 25 amperes of heating current, we find that the calculated values of the potential differences are greater than the measured ones.

TABLE I

Values of potential differences for electrolytic currents adding the heating current. (I = 2.0 amps.)

No.	x mA.	$(I^2+Ix+x^2/3)$ (Amps)^2	Re ohms	$(I+x/2)$ Amps.	Calculated P.D. Volts	Measured P D Volts
1.	10	4 020	1.0425	2 005	2.089	2 0764
2.	20	4 040	1 0427	2 010	2 095	2.0700
3.	50	4.100	1 0430	2.025	2 112	2.0738
4	100	4.203	1.0440	2.050	2 142	2.0968
5.	200	4.413	1.0460	2.100	2 197	2 1508
6.	300	4.630	1.0480	2 150	2 253	2.2076
7.	400	4 850	1.0502	2 200	2 311	2 2580
8.	500	5.080	1.0530	2.250	2 370	2.3194
9.	600	5.320	1 0560	2.300	2.429	2.3764
10.	800	5 810	1 0590	2 400	2 543	2 4972
11.	1000	6.333	1.0650	2.500	2 663	2 6114

TABLE II

Values of potential differences for electrolytic currents opposing the heating current. ($I = 2.0$ amps.)

No	x mA	$(I^2 - Ix + x^2/3)$ (Amps)^2	R ohms	$(I - x/2)$ Amps.	Calculated P.D. Volts	Measured P.D. Volts
1	10	3.980	1.0420	1.995	2.078	2.0626
2.	20	3.960	1.0417	1.990	2.073	2.0486
3	50	3.900	1.0410	1.975	2.056	2.0226
4.	100	3.803	1.0400	1.950	2.028	1.9938
5.	200	3.613	1.0382	1.900	1.972	1.9400
6.	300	3.430	1.0365	1.850	1.917	1.8880
7.	400	3.253	1.0347	1.800	1.862	1.8394
8.	500	3.083	1.0310	1.750	1.805	1.7900
9.	600	2.920	1.0290	1.700	1.750	1.7398
10.	800	2.613	1.0260	1.600	1.642	1.6392
11	1000	2.333	1.0200	1.800	1.531	1.5308

The difference in both the cases should be equal to $R_e i'_\beta$. However we find that this difference $R_e i'_\beta$ in calculated and measured values goes on increasing in the case of $R_e(I+x/2)$ values whereas it decreases and even becomes zero in the case of $R_e(I-x/2)$ which requires an explanation. The explanation is not far to find. We know that the conductivity of an electrolyte increases with the rise in temperature (Glasstone 1956).

$$\Delta_t = \Delta_{25}[1+k(t-25)]$$

where Δ_t and Δ_{25} are the equivalent conductivities at t°C and 25°C and k is a constant for an electrolyte. Therefore in the case of $R_e(I+x/2)$, Fig 3 the temperature of the wire and hence the conductivity of the electrolyte goes on increasing and therefore, the difference between calculated and measured values goes on increasing with the electrolytic current. Whereas, in the case of $R_e(I-x/2)$, Fig 4 the temperature of the platinum wire goes on decreasing and hence i'_β becomes very small thereby the calculated and measured values almost coincide.

In addition to these we have one more point of interest to consider and that is the electrode heating depending upon the electrolytic current densities. Beck and Putnam (1951) showed that large temperature differences (ΔT) between anode and the electrolyte were observed and therefore, due to the electrode heating also there will be an increase in the value of R_e and hence the measured values of the potential differences are found slightly higher than the calculated potential differences for the curves for which i'_β is small. In other cases where i'_β is large this effect is masked.

CONCLUSIONS

From the above discussion it becomes quite clear that when the electrolytic current is superimposed upon a current carrying conductor, point to point variation of the current along the wire should be considered. Thus when the electrolytic current is adding the heating current, the potential difference across the wire is

$$R_e\,(I+x/2)$$

and when the electrolytic current is opposing the heating current, the potential difference becomes

$$R_e\,(I-x/2)$$

where R_e is the effective resistance of the wire at that time

When the electrolytic current is adding the heating current, the difference in the calculated and measured potential differences is due to the increase in the leakage current, as the conductivity of the electrolyte increases with the increase in the electrolytic current as reported earlier by Gaur *et al.* and rise in temperature of the electrolyte in the vicinity of the wire When the electrolytic current is opposing the heating current the conductivity of the electrolyte decreases with the decrease in the temperature of the electrolyte in the vicinity of the wire

This difference is certainly not due to the change in the heat transfer coefficient or resistance of the wire, as reprted by Bhand *et al.*

With these results it is therefore concluded that in all experiments of heat transfer where a naked wire is dipped in a liquid, the measure of the resistance of the wire is erroneous due to the leakage of current in the liquid Also when the temperature of the liquid near the wire rises, the molecules of the liquid become mobile, the conductivity of the liquid is bound to increase, which increases the leakage current. Hence the measure of the resistance will not give the correct temperature of the wire.

Therefore, in all such experiments for correct estimation of the resistance and hence the temperature of the wire, a suitable correction will have to be applied for the fraction of the leakage current passing through the liquid.

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